Distributed Large-Area Macroelectronics

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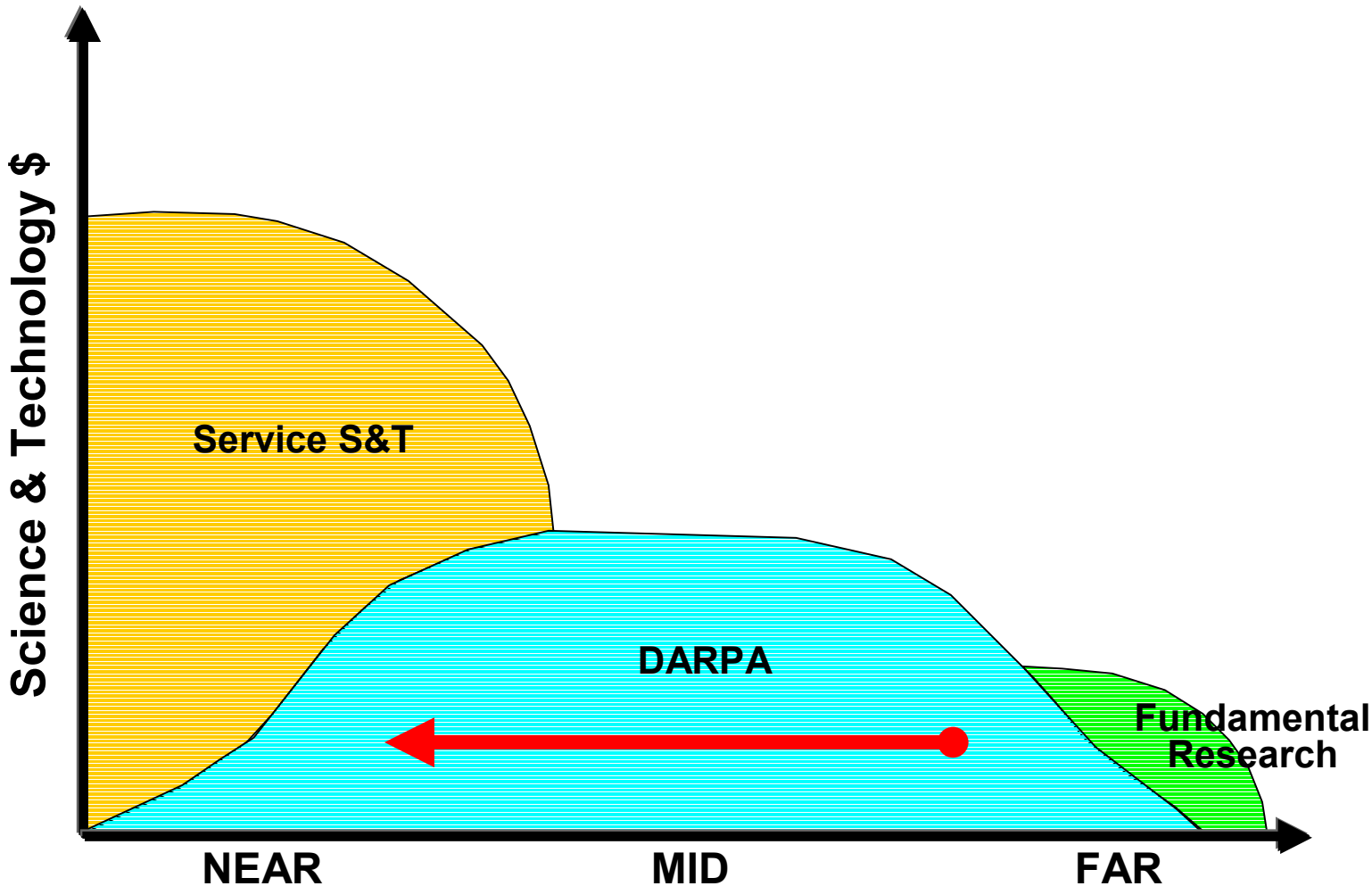
April 25, 2003

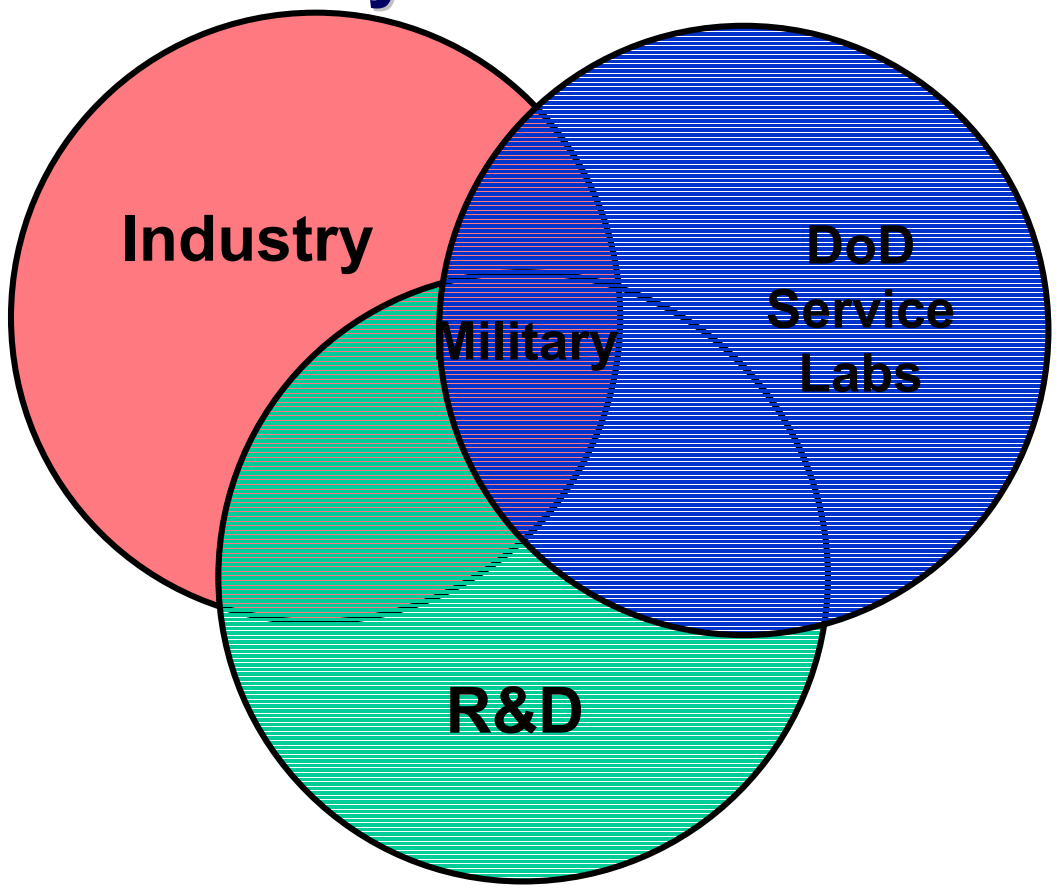
DARPA Role in Science and Technology



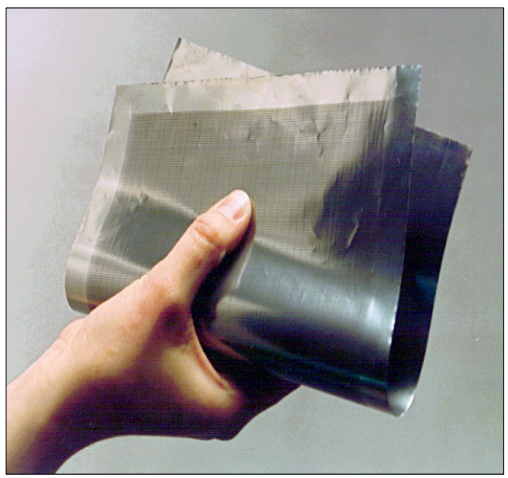
Who Do We Work With…

And How… And Why???

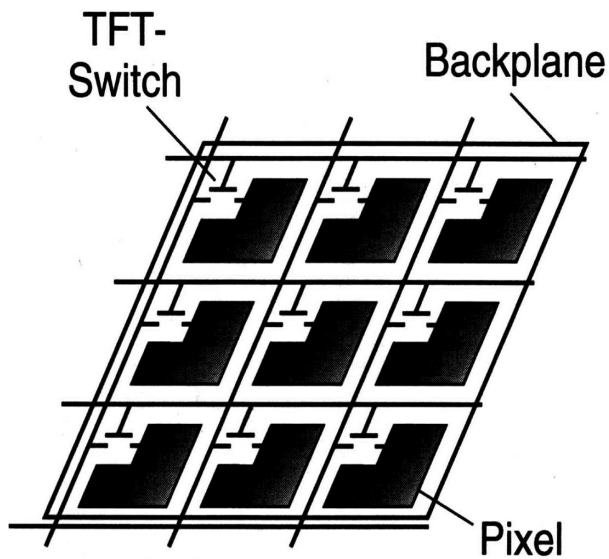
- DARPA is a projects agency.
- Understand how to manage high payoff projects with significant technology risks.
  - Seeks the best ideas for greatest impacts
  - Encourages transitions
  - Creates capabilities
  - Often includes equipment, materials, etc.
- Mainstream commercial industry, Defense industrial firms, Academia, National Labs, Defense Labs, Small Businesses.
  - Look for leverage and teaming as appropriate
- Can successfully form research networks among program community where the net impact >> value of the funded work.
- To deliver the most advanced technology options to the DoD.



Large Area, Flexible Macroelectronics



Moderate performance electronic circuits can be made on rugged yet flexible surfaces, such as 1-mil stainless steel foil or 3-mil sheet glass, as well as variety of plastics



The basic circuit element of large area electronics is the “pixel” analogous to a display backplane. A typical pixel contains transistors that drive sensor or actuator functions. Higher performance TFTs will enable control and compute functions and RF in the 10s of MHz range.

Macroelectronics: Definitions

- **Macroelectronics:**
  - **Device/circuit technology not driven by need for smallest possible dimensions, but rather large area and/or flexible form factor (Nominal features in 1-10 um regime)**
  - **Enables distributed and flexible electronics**
- **Distributed Electronics:**
  - **Electronics (ideally macro) spread over area/volume to conserve space/weight or achieve enhanced functionality (must be big to be effective)**
- **Conformable/Flexible Electronics:**
  - **Electronics fabricated on substrate that allows shaping to surface or increased ruggedness against mechanical damage (foldable/rollable)**
- **Flexible Substrates:**
  - **Support substrate with TFT electronics fabricated/transferred directly onto surface**

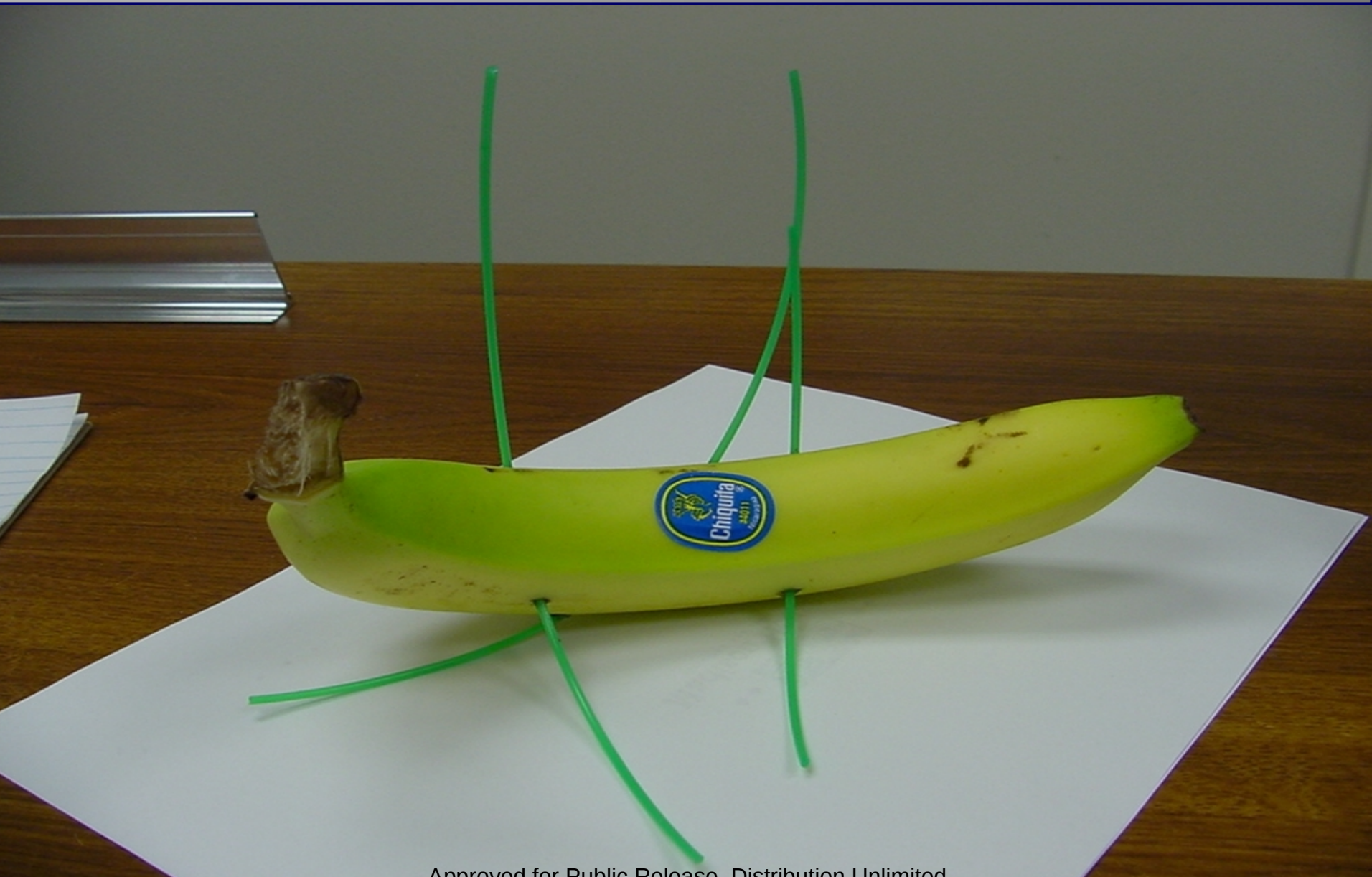
Why Macroelectronics?

- **Not all systems benefit from scaling**
  - Displays
  - Sensors
  - Human I/O
- **Microelectronics is not always the best solution**
  - Too costly
  - Too small
  - Too fragile
- **Macroelectronics possible solution, but...**
  - Material/device characteristics must be adequate
  - Manufacturing process must be (much) cheaper
  - Application and processing must be for large area
  - Substrate must provide novel form factor (flexible, lightweight)

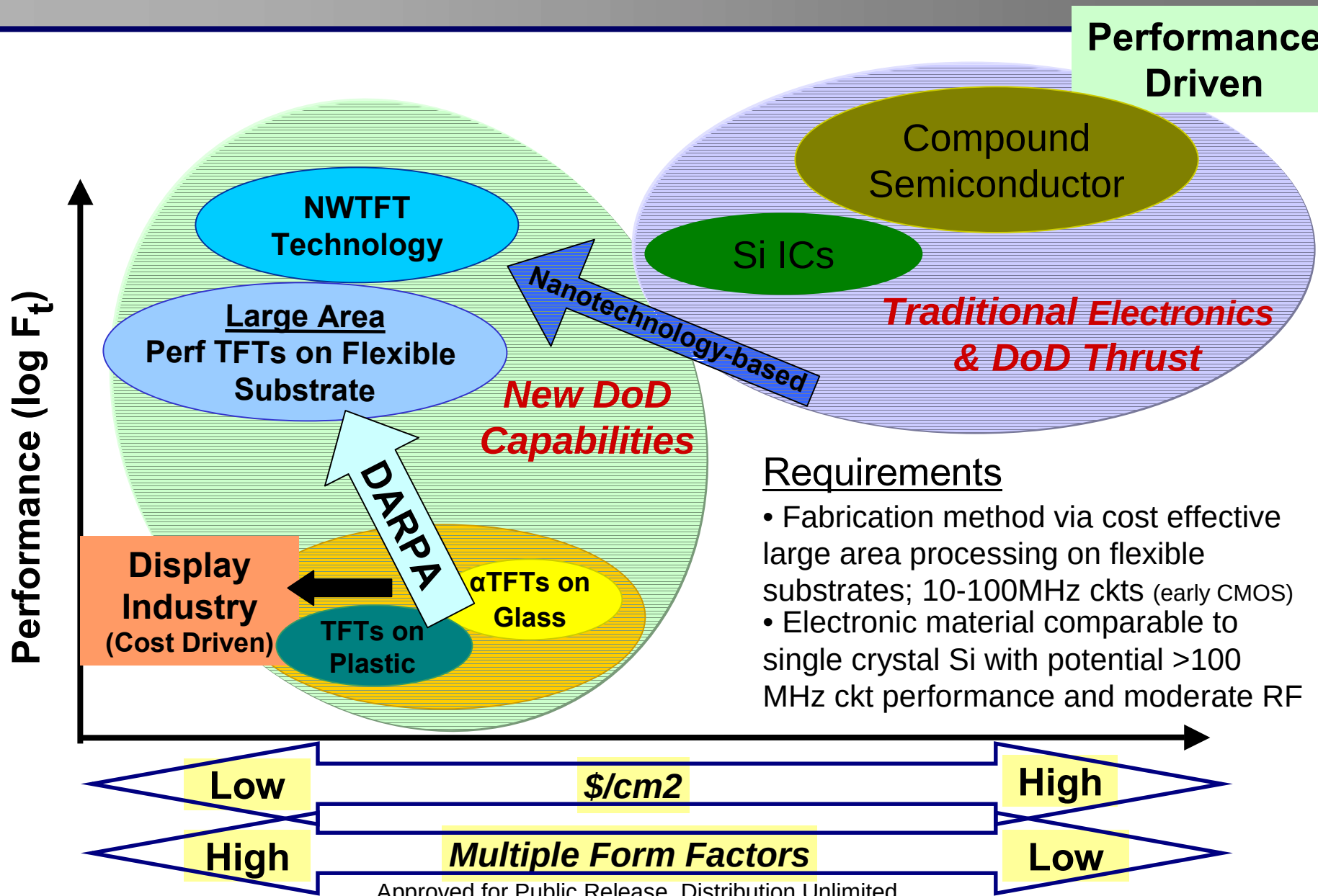
What Macroelectronics Is Not
(but hopefully will benefit from)

- Display and photovoltaic technology
- E-textiles technology (fabric substrates ok)
- Direct write of passive components (MICE)
- Nanoimprint Lithography development
- Molecular/bio-inspired technology

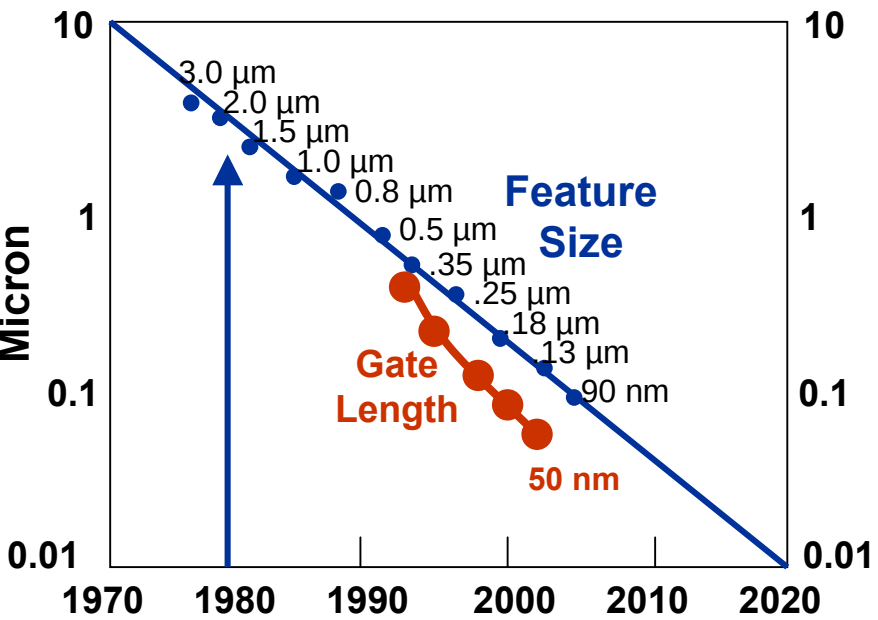
It is Definitely Not This: Nana(o)electronics

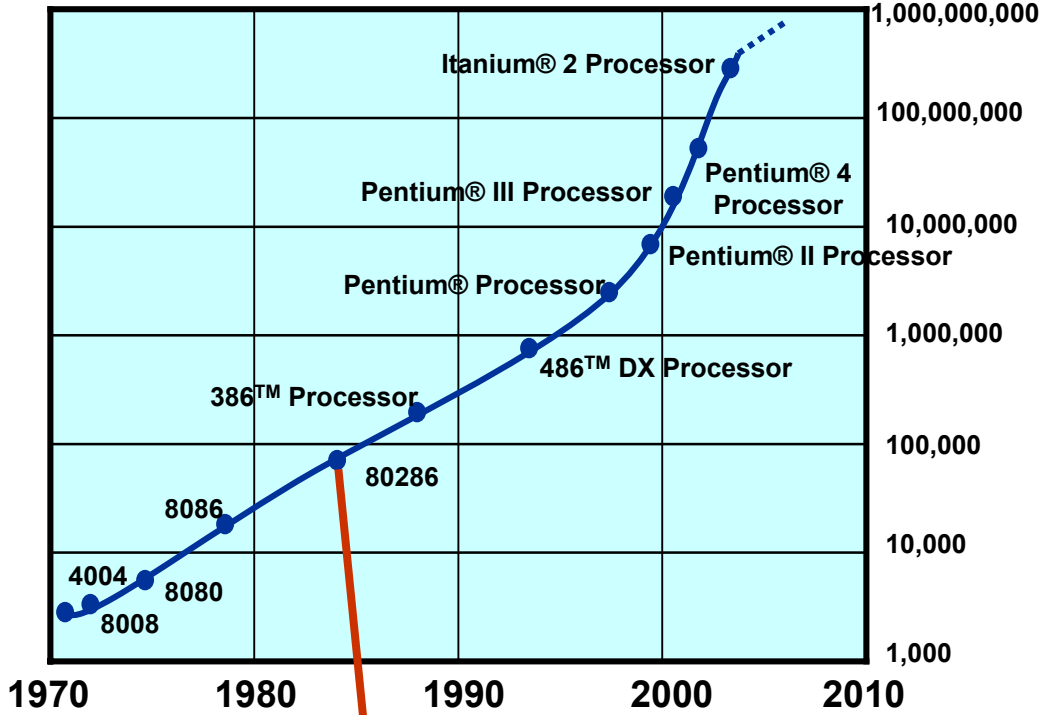


Macroelectronics Opportunity Overview



2 µm Technology



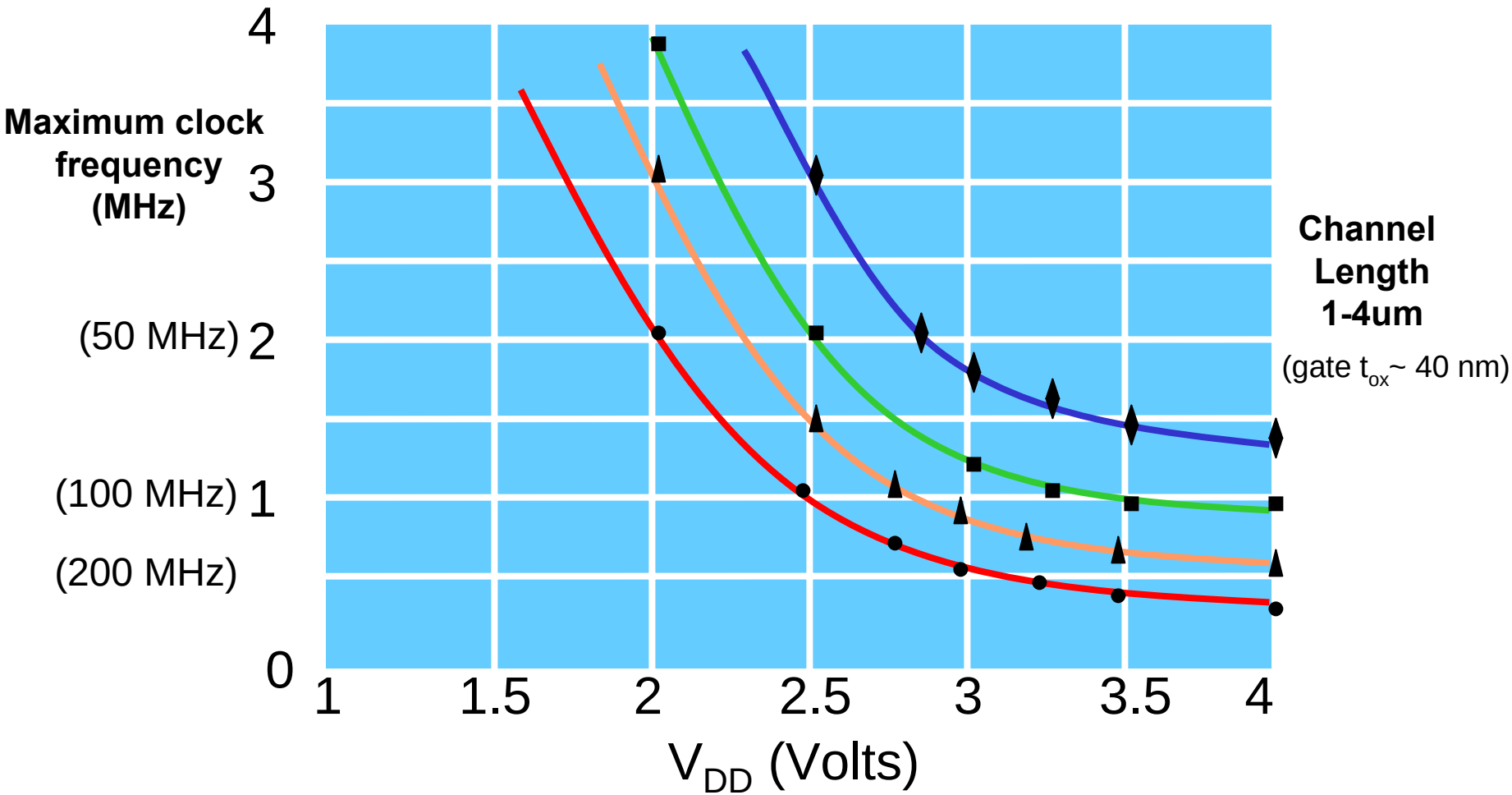


Older, slower technology.
But cheap!!

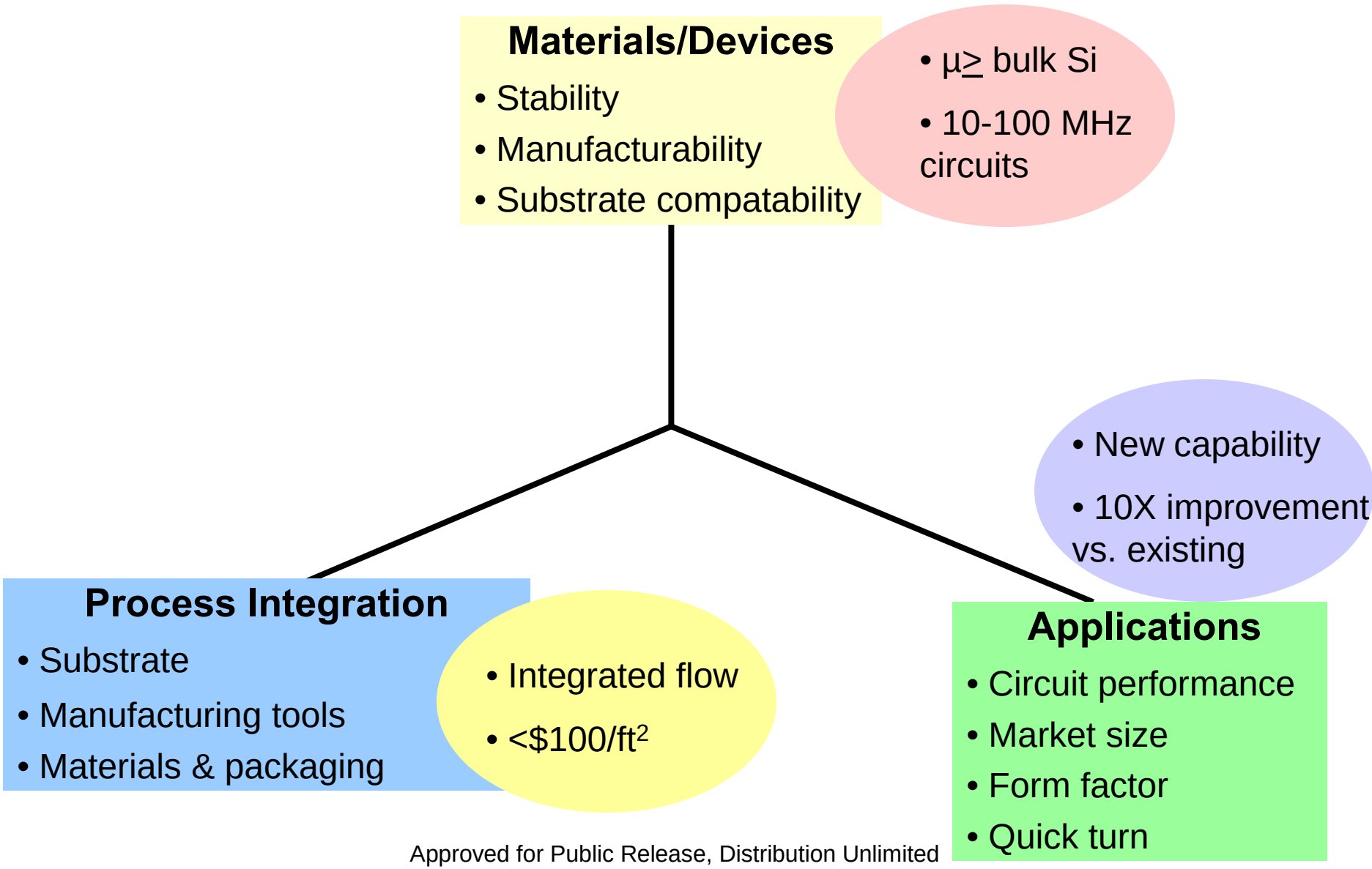
80286
- 100,000 Transistors
- 1.5 mm Technology
- Speeds from 6MHz to 20 MHz
- Capable of addressing 16 MB

Low Temperature Polysilicon

Ring Oscillator Performance



Vectors for Improvement of Macroelectronics



Macroelectronic Options

- TFT approaches that include a-Si, low-temperature p-Si, or organic devices fabricated directly on flexible substrate
- TFTs processed on temporary substrate for ease of manufacture with subsequent transfer to thin, lightweight, flexible support
- Devices fabricated at macro level but with novel materials/structures to overcome existing limitations

Task Description

- **Task 1: Devices**
  - **Phase I: Emphasis on overcoming current aSi, LTPS limits**
    - **Looking for major advance in performance**
  - **Phase II: Optimization and integration**
  - **Phase III: Demo of application enabled by capability**
- **Task 2: Tools/Methods**
  - **Phase I: Processes not limited by current emphasis on display application but rather high performance TFT macro manufacturing**
  - **Phase II: Optimization and integration to include devices**
  - **Phase III: Use in fab of application**
- **Task 3: Applications**
  - **Phase I: Search for "killer apps" and what would be required of Macro to address**
  - **Phase II: Detailed study of few candidates to select which go to design phase**
  - **Phase III: Design, fab, test, and evaluate benefits**

Task 1: Materials Development and Device Fabrication for Macroelectronics

- Significantly advance the performance of thin film transistors fabricated on flexible substrates
- Purpose is to enable the use of these devices in demanding circuit applications
- Performance comparable to bulk Si devices of comparable size is goal
- Such performance may not be possible with conventional materials and processes
- Novel ideas may be required
  - transfer of large area, TFT circuits from temporary substrates to the desired flexible substrates
  - application of advances in nanostructured materials and/or combinations of materials
  - interconnection of functional blocks via non-electrical means
- Fabrication methods should be considered with regard to establishing process flow

Task 2: Process Integration for Cost Effective Manufacture of Macroelectronics

- Tools and methods must be available to fabricate these enhanced devices
- No inherent desire for either “microelectronics-like” or “printing-like” processes
- Tools/methods should be selected based on ability to provide high performance TFTs
- Initial development may be focused on conventional TFT materials and processes
- Flexibility to incorporate or facilitate novel materials/processes for significant performance enhancements should be explicitly considered

Task 3: Analysis and Demonstration of Novel Applications of Macroelectronics

- Consideration of what type of applications might be addressed with Macroelectronics is a critical element
- Successful achievement of the goals will provide a capability that does not currently exist
- There are yet no clear answers as to what performance and cost metrics are required
- Real benchmarks that represent solutions to real problems effective way to drive development and implementation of the technology

Military Applications

- Electronically steerable antenna arrays
  - Unfoldable man-portable antennas
  - Expandable antennas for satellite applications
  - Conformal airborne, space-based radar or EW
- Tunable frequency selective surfaces for enhanced electromagnetic performance
- Flexible, large-area electronic sensors for chem/bio and radiation detection
- Adaptive surfaces to modify surface properties
- Conformable electronics to monitor surface

Teaming

Experience has taught us that one of the best ways to achieve the goals set forth in the BAA is the teaming of good ideas. Teaming is not mandatory, but strongly encouraged. A website has been made available to make teaming easier. Please go to:

https://www.davincinetbook.com/macroelectronics

BAA Objectives

- To develop materials and transistor technologies that are compatible with :
  - Low cost fabrication (roll to roll processing, printing)
  - Weight/space constrained applications
  - Integration in/on large area/or flexible substrates
- To demonstrate process technologies needed for successful implementation
- To identify possible breakthroughs to enable
  - Drastic cost reductions
  - Significant performance enhancements
- To conduct research in context of applications that will both drive technology development and provide novel, previously unavailable capability
- Commercialization: not driver, but a factor

- **Best technology for DoD is all that counts**
  - **I have a wife and 2 kids, being told I am wrong is not a novel experience**
- **If you think BAA terms are wrong, do what you think is right. Just give a reason!**
  - **Solving problems is important, not Bob's ego**

Other Initiatives

The Army has announced its intention to create and sponsor a university led center to develop flexible display science and technology solutions.

Summary

- Variety of potential applications for large area or distributed, very low cost electronics in flexible form factor
- Several candidate materials systems available with reasonable material/device characteristics as baseline
- Numerous manufacturing processes and tools consistent with overall requirements are available for process integration
- Not clear that significant improvement in device/circuit performance possible based on existing technology, but new applications are expected
- Significant macroelectronics advancements need a compelling driver that is “harder” than displays
- Much excellent work continues to be done, but breakthrough may be enabled by application of nanotechnology for macro devices

Thank You for your interest in DARPA's Macroelectronics Program